NEW YORK UNIVERSITY
NYU STERN
LEONARD N. STERN SCHOOL OF BUSINESS

Department of Finance
Working Paper Series 1998

FIN-98-019

The Effect of Leverage on Bidding Behavior: Theory and Evidence from the FCC Auctions

Matthew J Clayton, S. Abraham Ravid

February 1998

This working paper series has been generously supported by a grant from

CDC Investment Management Corporation

The Effect of Leverage on Bidding Behavior: Theory and Evidence from the FCC Auctions†

By

Matthew J. Clayton*

And

S.Abraham Ravid**

Revised: January 1998
Preliminary

† We thank Ron Harstad for helpful comments and extremely helpful discussions concerning the FCC auctions. We thank Joshua Rosenberg and Matt Spiegel for useful comments and suggestions, and Bob Ewalt for research assistance.
* Department of Finance, Stern School of Business, New York University, 44 West Fourth Street, New York, NY 10012-1126. e-mail: mclayton@stern.nyu.edu
** Department of Finance, Faculty of Management, Rutgers University, Newark, New Jersey.

Abstract

This paper investigates how firm bidding behavior in various auctions is affected by capital structure. A theoretical model is developed where the first price sealed bid and second price sealed bid auctions are examined in situations where the firms are either competing for an asset with a common value or a private value. Findings include that in the presence of exogenous and symmetric debt, the revenue equivalence theorem no longer holds, and hence, there may be an optimal auction or set of auctions that yield the maximum expected revenue to the seller. In addition, as debt level increases this, in general, gives the firm incentives to decrease its bid. Due to a lower bid function, this gives the competition incentives to also decrease their bid. Thus, we [1]would expect a firm's bid to be a function of both its own debt level and the competition debt level, and an increase in either should result in a decrease in the firm's bid. These results are investigated in the recent FCC auctions. The empirical evidence is consistent with the theoretical model. Debt levels of the bidding firm and the competition are both important determinants of the highest bid a firm is willing to submit in the auction, and higher debt levels (by the firm or its competition) lead to lower bids.

1

The Effect of Leverage on Bidding Behavior: Theory and Evidence form the FCC Auctions

Recent decades have witnessed an increasing interest in the interactions of production and financial decisions. There have essentially been two approaches to the issue. One approach has sought to find the link between production and financial decisions in taxes and in bankruptcy states. Papers written by Hite (1978), De-Angelo and Masulis (1980), Dotan and Ravid (1985) and Dammon and Senbet (1988) demonstrate that investment and financing decisions jointly determine the expected tax liability and the expected bankruptcy cost paid by firms.

The other approach has been to view leverage as a strategic variable, affecting firm production choices much in the same way delineated by Jensen and Meckling (1976) and Myers (1977). Brander and Lewis (1986), Maksimovic (1988), Clayton (1997) and others suggested that debt could affect quantity produced in oligopoly settings and that it would impact decisions such as entry and investments. While the latter approach seems to be supported by some recent empirical evidence (see Chevalier (1995) and Phillips (1995), there may be other explanations for these empirical findings (see Ravid (1997)).

There is another troubling issue – if indeed firms produce sub-optimally because of leverage, as suggested, for example, by Brander and Lewis (1986), why should these firms not restructure and increase firm value (see Dybvig and Zender (1991) for arguments along these lines). Therefore, one would expect to find strategic effects much more in the short run, where firms may not easily or cheaply restructure than in the longer run, where restructuring may be preferable to the continuation of sub-optimal production.

Our paper discusses a particular type of short run production interaction, namely the bidding behavior of firms in auctions. We first demonstrate that under most reasonable assumptions on auction structure, levered firms will tend to under-bid (bid a lower price) compared to unlevered firms. This is not trivial, since in auction literature different structures typically yield different patterns of behavior. We also demonstrate that leverage will cause a violation of the revenue equivalence theorem. Once leverage is considered, different auction mechanisms may generate different expected revenue.[2] In the empirical part of the paper, we investigate recent FCC spectrum auctions and find that the behavior predicted by the theory seems to be consistent with firm bidding strategies in these auctions.

[2] We maintain all the assumptions of the revenue equivalence theorem.

Some Auction Theory Background

Vickrey (1961), under simplifying assumptions, illustrates that the open "English" and the first price sealed bid auctions provide equal expected revenue to the seller. The assumptions include that each bidder's valuation is an independent draw from an identical uniform distribution, and that all players are risk neutral. Myerson (1981) and Riley and Samuelson (1981) expand on Vickrey's results and demonstrate that, under less restrictive assumptions, several other auctions generate equivalent expected revenue to the seller. Thus, the revenue equivalence theorem asserts that the open "English", first price sealed bid, second price sealed bid, and descending Dutch auctions yield the same expected revenue to the seller. The assumption of risk neutrality is maintained. The bidders' valuations must be independent draws from an identical distribution; however, this distribution need not be uniform. This implies that when a seller wishes to allocate a good through an auction, the expected payment is the same regardless of auction procedure.

Various papers have investigated the effects of relaxing the assumptions of the revenue equivalence theorem. Holt (1980), Riley and Samuelson (1981), and Maskin and Riley (1984) demonstrate that revenue equivalence fails to hold when bidders are risk averse. They show that the first price sealed bid auction generates greater expected revenue than the English auction when the bidders are risk averse. Conversely, risky debt causes shareholders to act as if they are risk seeking by introducing convexities into their payoff function. Consequently, when bidding firms have risky debt, English auctions provide more revenue than the first price sealed bid auction.

Milgrom and Weber (1982) show that when bidders' values are affiliated rather than independent, then an English auction yields higher expected revenue than first price sealed bid auction. Maskin and Riley (1994) demonstrate how revenue equivalence breaks down when the bidders' valuations are asymmetric. Furthermore, either the first price sealed bid auction or the English auction provides higher expected revenue, depending on the type of asymmetry in the bidders valuations. This paper adds to the cases in which the revenue equivalence theorem fails to hold.

Revenue equivalence will fail if levered firms act to maximize equity value rather than total firm value. Furthermore, we demonstrate that when firms have risky debt, the expected revenue generated by the seller in the open "English" and in the second price sealed bid auctions exceeds the expected payment in a first price sealed bid auction. Thus, there may be an optimal auction mechanism a seller should choose when the participating firms have risky debt outstanding.[3]

[3] It is not uncommon for firms that participate in auctions to go bankrupt. For example, in 1989 Pennsylvania Shipyards defaulted on its contract to produce four tankers for the Navy. The contract was

The rest of the paper is organized as follows. Section 2 describes the basic private value model that will be examined under different auction mechanisms. The equilibrium bidding behavior in the first price sealed bid auction and the second price sealed bid auction are determined. Section 3 examines the common value auction. Section 4 presents the data and section 5 provides the empirical results. Section 6 concludes.

1 Private Value Auction

BASIC MODEL

This section describes the basic model used in the private value auctions that are considered. There is one seller, who wants to sell a good. There are two firms for which the acquisition of the good would be valuable (clearly, in our empirical data very often there are more than two competitors. However, the effects analyzed here will generalize to n competing firms). The seller (in our empirical work, the Federal Government) conducts an auction to determine which firm will receive the good. The payment by the winning firm is also determined by the auction mechanism. All players are risk neutral, and the firms make bids to maximize their equity value.

The value to firm i ($i = 1,2$) of acquiring the good is v_i, which is distributed uniformly between 0 and V. The value realization of each firm is assumed to be an independent draw from the above distribution. Prior to the bidding stage, each firm observes its own value, however, only the distribution of the competing firm's value is known. Firm i has debt outstanding with face value D_i which must be paid prior to shareholders receiving any payoff. The debt level of each firm is common knowledge. Each firm is assumed to have cash on hand, c_i. It is also assumed that $D_i > c_i > V$. If a firm cannot pay debtholders in full, then shareholders' payoff is zero.

In each auction the firms compete though a bidding procedure. The strategy of firm i will be a bid, $b_i(.)$, as a function of the firm's own value, v_i, the firm's own debt level D_i, the firm's cash on hand c_i, the competing firm's debt level D_j, the competing firm's cash on hand c_j, and what the firm believes is the distribution of the competing firm's value, $f(v_j)$. At the conclusion of the bidding process, the contract is awarded to a firm based on the rules of

put up for bid again and awarded to Tampa Shipyards in Florida (owned by George Steinbrenner). Each time the contract was awarded the Navy had concerns about the winning firm's ability to complete the project due to financial difficulties. In 1993 the Navy terminated the contract with Tampa Shipyards. According to the Chicago Tribune, "(Derek) Vander Schaff (The Defense Department's inspector general), said Steinbrenner's Shipyard used its first 12 million in payments from the Navy to pay off its own loan rather than to hire a labor force, in order to shift the risk of default losses from itself to the Navy", see the Chicago Tribune 5/3/95, p.15.

the auction procedure. The firm that wins the auction receives the good for a payment, p, determined by the auction mechanism. Throughout this paper it is assumed that firm i wins the auction. Firm i receives profits of v_i - p, and firm j receives zero profits from the auction. Firm i must payoff its debt, D_i, and its shareholders receive any residual profits. The debtholders of firm i receive $\min\{v_i+c_i-p,D_i\}$, and firm i's shareholders are residual claimants who receive $\max\{v_i+c_i-p-D_i, 0\}$. The debt holders of firm j receive the cash c_j. Since $D_j>c_j$ the shareholders of firm j receive nothing.

We determine Nash equilibrium bidding strategies. Each firm's bid function is a best response to the competing firm's strategy. Thus, given one firm's bid function the rival firm chooses its bid function to maximize the expected payoff to its shareholders. In equilibrium, no firm has an incentive to change their strategy. Let $\pi_i[b_i(.), bj(.)]$ denote the expected payoff realized by the shareholders of firm i as a functions of the bidding strategies. The bid functions $\hat{b}_i(.)$ and $\hat{b}_j(.)$ are equilibrium bid functions if for all b_i (.)

$$\pi_i[\hat{b}_i(.),\hat{b}_j(.)] \geq \pi_i[b_i(.),\hat{b}_j(.)]$$

and for all $b_j(.)$

$$\pi_j[\hat{b}_i(.),\hat{b}_j(.)] \geq \pi_j[\hat{b}_i(.),b_j(.)].$$

The descending Dutch auction is strategically equivalent to the first price sealed bid auction. Under the assumptions of the model, the outcome of the English auction is identical to that of the second price sealed bid auction.[4] Thus, only first price and second price sealed bid auctions will be compared in this paper.

FIRST PRICE SEALED BID AUCTION

Symmetric debt

The first auction mechanism that will be considered is the first price sealed bid auction. In this auction the two firms submit their bids to the buyer simultaneously. The firm which submits the highest bid wins the auction. If both firms submit equal bids, the winner is determined randomly with each firm having an equal chance of winning. The payment for the good, p, is equal to the winning bid, $p = \max\{b_i,b_j\}$. If $b_i>b_j$ than firm i wins the auction and pays the price $p = b_i$ to the seller. The firm receives the value v_i from the good, and is left with assets of $v_i - b_i + c_i$ to distribute to their claimants. The debtholders payoff is $\min\{v_i-b_i+c_i,D_i\}$, and the shareholders payoff is $\max\{v_i-b_i+c_i-D_i,0\}$. The firm with the lowest bid loses the auction and receives no additional profits. A strategy for firm i is a bid function $b_i(.)$ based on its own realized value, v_i, the debt levels of both firms, D_i ,D_j , the cash on hand of both firms, c_i,c_j, and its prior belief of the distribution of the competing firm's value

[4]See Milgrom (1989) for an illustration of the correspondence between these auctions.

and bid function. A Nash equilibrium is a bid function for each firm, where each firm is maximizing the expected payoff to shareholders given the bid function of the competing firm. The bid functions $\hat{b}_i(.)$ and $\hat{b}_j(.)$ are equilibrium bid functions if for all $b_i(.)$

$$(v_i-\hat{b}_i(.)+c_i-D_i)*\text{Prob}\{\hat{b}_i(.)>\hat{b}_j(.)\}+(1/2)*(v_i-\hat{b}_i(.)+c_i-D_i)*\text{Prob}\{\hat{b}_i(.)=\hat{b}_j(.)\}$$
$$\geq (v_i-b_i(.)+c_i-D_i)*\text{Prob}\{b_i(.)>\hat{b}_j(.)\}+(1/2)*(v_i-b_i(.)+c_i-D_i)*\text{Prob}\{b_i(.)=\hat{b}_j(.)\}$$

and for all $b_j(.)$

$$(v_j-\hat{b}_j(.)+c_j-D_j)*\}\ \text{Prob}\{\hat{b}_j(.)>\hat{b}_i(.)+(1/2)*(v_j-\hat{b}_j(.)+c_j-D_j)*\ \text{Prob}\{\hat{b}_j(.)=\hat{b}_i(.)\}$$
$$\geq (v_j-b_j(.)+c_j-D_j)*\text{Prob}\{b_j(.)>\hat{b}_i(.)\}+(1/2)*(v_j-b_j(.)+c_j-D_j)*\text{Prob}\{b_j(.)=\hat{b}_i(.)\}.$$

The intuition of this expression is straightforward - a bid function is optimal if the expected gain from winning plus the expected gain if a draw occurs are maximized. It is not a trivial decision for a firm to choose a bid function.

A firm would not want to bid above its value because if it does and wins the auction it would make negative profits. If the firm submits a bid greater than or equal to its value of the good plus its debt level minus the cash on hand ($b_i \geq v_i+D_i-c_i$), then if the firm wins the auction there will be no residual profits left for shareholders. In fact if $b_i > v_i+D_i-c_i$,then upon winning the contract the firm won't have enough profits to completely payoff the outstanding debt. For this reason, a firm that chooses a bid to maximize the expected payoff to shareholders will have $b_i < v_i+D_i-c_i$. As the firm decreases its bid from $b_i = v_i+D_i-c_i$ the probability of the firm winning the auction decrease, but the payoff the shareholders receive conditional on the firm winning increases. The firm will decrease its bid below $v_i+D_i-c_i$ trading off these two effects until the expected payoff to shareholders is maximized given its value realization.

Consider the case when firms have an identical amount of debt outstanding ($D_i=D_j=D$) and the same amount of cash on hand ($c_i=c_j=\mathbf{c}$). Assume that firm j has a bidding strategy of $b_j(v_j,D)$. Firm i's best response is to choose b_i to maximize the following equation:[5]

[5]There is an additional term in equation (2.1) to account for the possibility of each firm submitting identical bids. As long as the equilibrium bid function is strictly monotonic in value then the probability of each firm submitting the same bid is zero. This is true because there is a continuum of possible valuations. It can be verified that this is true at the Nash equilibrium bidding strategies; thus, the additional term in (2.1) is zero.

$$\max_{b_i}(v_i + c_i - b_i - D_i) \times$$

(2.1) $\max_{b_i}(v_i + c_i - b_i - D_i) \times \Pr\{b_i > b_j(.)\}$.

Solving for the optimal response of firm i and exploiting the symmetry of the problem, yields the following equilibrium bid function:[6]

(2.2) $b_i(c_i,D) = \frac{v_i}{2} - (D_i - c_i)$, $(i = 1,2)$.

Equation (2.2) describes the Nash equilibrium bidding behavior for the first price sealed bid auction. Each firm will bid one half of their private value of the object minus the debt overhang. When the firms have no *risky* debt outstanding, i.e., $D_i = D_j = \mathbf{D} \leq c_i = c_j = c$, then the symmetric equilibrium bid function is: $\frac{v_i}{2}$.[7] This is a well-known result obtained when two symmetric, all equity, risk-neutral firms with private, uniformly distributed values participate in a first price sealed bid auction.

When firms have risky debt outstanding, i.e. $\mathbf{D} > c$, then the firms bid one half their valuation minus the amount of risky debt outstanding.[8] The bid functions are symmetric, thus the firm with the highest realized value submits the maximal bid, and wins the auction. The expected maximum value is $\frac{2V}{3}$, which is the expected value of the first order statistic.[9] The expected maximum bid, which is the bid of the expected maximum value is $\frac{V}{3} - (D_i - c_i)$. This is the expected revenue to the seller. The winning firm expects to make a profit of $\frac{V}{3} + (D_i - c_i)$, and each firm has a fifty percent chance of winning, so the *ex-ante* expected profit of each firm is $\frac{V}{6} + \frac{(D_i - c_i)}{2}$.

[6]See the appendix for the derivation of this bid function.

[7] It should be pointed out that a lack of risky debt does not imply symmetry of cash on hand. However, it is easily verified that if $c > D$ for each firm then $b_i = \frac{v_i}{2}$ is the equilibrium bid function for each firm.

[8]Note, the firms are not restricted to make positive bids.

[9]See Rice for the formula that determines the probability density function of the order statistics.

Proposition 1. *The Nash equilibrium bids, b_i, and b_j, are decreasing in **D**.* $\frac{\partial b_i}{\partial D} < 0, \frac{\partial b_j}{\partial D} < 0$.

PROOF: Follows immediately from the first derivative when equation (2.2) and the corresponding bid function for firm j are differentiated with respect to **D**.

Proposition 2. *The expected high bid, and thus the expected payment to the seller is decreasing in **D**.*

PROOF: Result follows from the derivative of the expected maximum bid.

Proposition 3. *Each firms' expected profits increase in **D**.*

PROOF: Result follows from the derivative of the expected profit equation.

Risky debt affects the bidding strategies of the firms. As the amount of debt that each firm has outstanding, D, increases the bidding functions of the firms decline. This decreases the expected revenue to the seller. This also increases the expected profits and the total value of the bidding firms. Although shareholders seek to maximize the value of their holdings, this latter result (proposition 3) is important to shareholders as long as debt is issued in a competitive product market. Assuming the debt holders pay a fair market value for the debt issued, any increase in profits accrues to the shareholders. This result assumes the firm holds c, the amount of cash on hand, constant. This would arise if the money raised in a debt issue is used to pay dividends or repurchase shares. Alternatively, the proceeds can be used to pay ongoing business expenses in lieu of an additional equity issue.

SECOND PRICE SEALED BID AUCTION

We now assume that the seller uses a second price sealed bid auction. In a second price auction, each firm submits a bid b_i, and the highest bid wins the contract. The winning firm pays the second highest bid to the seller for the good. A strategy for firm i is a bid as a function of the firms realized value v_i, the debt level of both firms (D_i, D_j), the cash on hand c_i, and its prior beliefs about the other firm's value. If firm i wins the contract (i.e. $b_i > b_j$) then firm i pays b_j to the government, and firm i's total payoff from the auction is $v_i - b_j$. If the firm does not win the contract then its payoff is zero.

In this auction mechanism the bid a firm submits affects the probability the firm wins the auction, but does not affect the payoff received if the firm wins. The payoff is determined by the competing bids. Shareholders of firm i are indifferent between submitting any bid $b_i \in (v_i - (D_i - c_i), +\infty)$ because their payoff is zero if the firm loses money. However, any epsilon payment to shareholders if the firm is not bankrupt, will allow us to limit bids to the more reasonable range of $b_i \in [v_i - (D_i - c_i)\ ,\ v_i]$, and a bid in this range dominates any other bid. Although with a higher bid the firm has a higher probability of winning, if the firm raises its bid above v_i it only adds to the chance of winning in instances where the payoff to the firm would be negative. The firm would not want to bid below $v_i - (D_i - c_i)$ because as the bid is decreased below $v_i - (D_i - c_i)$ the firm decrease the probability of winning over states where shareholders receive a positive payoff. There are multiple equilibria to the second price auction. Any pair of bids (b_i, b_j) such that $b_i \in [v_i - (D_i - c_i)\ , v_i]$, and $b_j \in [v_j - (D_i - c_i)\ , v_j]$ is a Nash equilibrium to the bidding game.[10] The results of the auction and the price of the good will depend on which Nash equilibrium is played.

Proposition 4. *The equilibrium bid of each firm is weakly decreasing in own debt level.*

PROOF: By assumption, the maximum equilibrium bid a firm can submit is its own valuation. This is true regardless of the debt level of the firm. The lowest equilibrium bid a firm can submit is its value minus its debt over hang, $v_i - (D_i - c_i)$. As a firm's debt level increases the lowest equilibrium bid decreases. Thus, an increase in debt level adds additional possible equilibrium bids, which are below the current possible equilibrium bids.

Proposition 5. *Across equilibria, expected revenue generated by the second price auction is bounded below by the expected revenue generated by the first price auction.*

PROOF: Suppose each firm chooses to bid the minimum equilibrium bid in the second price auction. In this case firm i will submit a bid of $b_i = v_i - (D_i - c_i)$. WOLG assume that firm i has the high value realization. The expected high value realization is $\frac{2V}{3}$. The expected bid firm i will submit is $\frac{2V}{3} - (D_i - c_i)$, and firm i will win the auction. We must now calculate the second order statistic to determine the expected value realization for the low firm (here assumed to be firm j). The expected second highest value is

$$\frac{V}{3}. \tag{2.5}$$

The expected bid of firm j is $\frac{V}{3} - (D_j - c_j)$. The expected second highest bid is the expected price that the winner pays, and the expected revenue to the seller. When both firms choose to bid the lowest possible equilibrium bid the expected low bid (and expected

[10] Multiple equilibria exist regardless of the number of bidders in the second price auction. The range of optimal bids for a firm does not depend on the rival's bid, and does not depend on the number of bidders. The firm is still indifferent between any bid within the specified range, and these bids dominant all other possible bids.

revenue to the seller) is $\frac{V}{3}$ - (D_j - c_j). This is the same expected revenue received in the first price sealed bid auction. This expected revenue is generated in the second price auction when each firm chooses the minimum possible equilibrium bid. If either firm choose to submit a bid which is not the minimum Nash equilibrium bid then the expected revenue received from the auction is strictly larger.[11]

2. Common Value Auction

FIRST PRICE SEALED BID AUCTION

The second major type of auction is a common value auction. Here the good sold has the same valuation (or the same probability distribution observed by all players) for all bidders, and consequently, bidding strategies may be very different from the private value auction. We demonstrate that in this case too, leverage will make a difference.

The model consists of two firms competing in a first price sealed bid auction for an asset of unknown value. Both firms have risky debt outstanding. Each firm receives a signal, which contains information regarding the value of the asset. After observing the signal each firm submits a bid, and the firm that submits the highest bid wins the auction. The winning firm makes a payment to the seller equal to their bid. Subsequent to taking possession of the asset, the true value can be observed. The firm's debtholders are paid and any residual profits accrue to the shareholders. The losing firm receives a payoff of zero from the auction.

Let D_i (i=1,2) be the amount of debt firm i has outstanding. Assume firm i has cash on hand of c_i. It is assumed that the cash on hand is enough to pay the bid of the firm, but less than the debt outstanding, $D_i > c_i > b_i$.[12] Each firm receives a private signal, $s_i \in S$, which is informative with respect to the value of the asset. Let $U(s_1,s_2)$ denote the expected value of the asset conditional on the signals observed by each firm. It is assumed that U(.) is increasing in both signals. If firm i wins the auction then, after payment of the bid is complete, the debt D_i must be paid, and the remaining profits accrue to the shareholders. If $U(.) \leq D_i - (c_i - b_i)$ then the shareholders receive

[11] The discussion so far has assumed that v is known, and hence the resulting equilibria reflected the under-investment problem of debt. If there is uncertainty in v, then issues of risk shifting would arise and bids could in principle go either way. However, the rigorous analysis of such issues is extremely difficult, and as a first approximation, one can surmise that values are known to a large extent. In the next section, the issue of risk is explored in a different set-up, and the result is that indeed, bids tend to decrease in leverage.

[12] If $c_i > D_i$ then the firm has zero risky debt outstanding, if $b_i > c_i$ then the firm is unable to participate in the auction due to in ability to pay the bid.

nothing.[13] Each firm submits a bid to maximize the expected value to the shareholders conditional on the signal received.

The order of the game is as follows:

1) Each firm receives a signal s_i
2) Firms simultaneously submit sealed bids b_i
3) The firm with the highest bid wins the auction
4) The winning firm realizes the true value of the asset.
5) Payoffs are determined.

The traditional method to solve the firm's problem in a first price sealed bid common value auction is to exploit the symmetry of the problem.[14] The firms are identical (either they have no debt, or they have the same amount of debt outstanding), and thus if they receive the same signal, they would submit the same bid. This, along with the assumption that a higher signal implies a higher expected asset value, means that the firm, which receives the highest signal, will win the auction. When choosing a bid, the firms use the fact that they win the auction if they have the highest signal. With this information they can compute the probability that they will win the auction conditional on the actual value of the asset. They can also calculate the expected value of the asset conditional on winning, which is less than the expected value of the asset conditional on their signal due to the fact that if they win, then the competing firm received a signal lower than their own. The expected value of the asset conditional on the signal s_i is simply the signal s_i (since the signal is an unbiased estimator of the true value). However, the expected value of the asset conditional on the signal s_i and the additional information that $s_i > s_j$ is less than s_i.[15]

This solution concept is no longer viable when firms have asymmetric debt levels. When firms have unequal debt levels it is not certain that the firm with the most favorable signal should win the auction. Hence the distribution of the signals cannot be used to calculate the probability that a firm wins the auction.

Let $\beta(s_j)$ be the bid of firm j given the signal received. Given this bidding strategy for firm j, the optimal bidding function of firm i, $b(s_i)$, can be determined. The expected profit to the shareholders of firm i, if the firm bids b_i when the signal s_i is observed is:

---

[13]$(c_i - D_i)$ is the cash left in the firm after the bid is paid. That cash can be used to pay down the debt. The remaining debt (which is $D_i - (c_i - b_i)$) must be paid out of profits from the asset prior to sharholders receiving any payoff.

[14]For example, see Willson (1977).

[15]For example, if both s_i and s_j were observed the expected value of the asset would be $(s_i + s_j)/2$ (since they are iid draws from a distribution with expected value v). Thus, if $s_i > s_j$, then $(s_i + s_j)/2 < s_i$.

(3.1)

The first term, $[U(s_i,s_j)+c_i - b_i - D_i]$ is the profit that the shareholders receive if the firm bids b_i, wins the auction, and $U(s_i,s_j) + c_i > D_i + b_i$. The next two terms are both indicator functions. The first indicator function takes the value of one when the cash on hand net the bid plus the value of the object is sufficient to payoff the debtholders, otherwise it is zero. The second indicator function takes the value of one when the firm wins the auction. If either of these functions is zero the shareholders receive a payoff of zero. When both of these functions are one then the shareholders receive the payoff equivalent to the first term on equation (3.1). These terms are integrated over all possible rival signals to generate the expected payoff to the shareholders when the firm bids b_i. Equation (3.1) is not differentiable; thus the theorems of monotone comparative statics are used to analyze the players responses.

Milgrom and Roberts (1990) and Vives (1990) analyze a class of games introduced by Topkis (1979) called supermodular games. A game is supermodular when each player's choice set is partially ordered and the marginal returns to increasing one player's strategy increases as the competitor's strategy increases.' If the player's choice set is multidimensional then the marginal returns to increasing one choice variable must be increasing in the other choice variables. Milgrom and Roberts and Vives show that supermodular games have non-empty set of Nash equilibria and provide conditions under which the minimum and maximum elements of the Nash equilibrium set are increasing in the underlying parameters. The following conditions must be satisfied for a game to be supermodular:

(A1) each player's strategy set is a complete lattice
(A2) the payoff function is upper semi-continuous in the player's strategy for a given competitor's strategy
(A3) the payoff function is suppermodular in the player's strategy for a given competitor's strategy
(A4) the payoff function has the single crossing property in own strategy and rival strategy.

If a supermodular game satisfies the single crossing property in own strategy and an underlying parameter for a fixed competitor's strategy, then in addition to having a non-empty set of Nash equilibria, the minimum and maximum element of the Nash equilibria set are nondecreasing function of the underlying parameter. Athey (1995) develops conditions, which insure that a stochastic objective function satisfies the single crossing property. (Theorem 5.1 pp. 30).

Proposition 6. *A firm's bid is non-increasing in own debt and competitors debt and non-decreasing in own signal.*

PROOF: See appendix.

It is easily shown that if $\beta(s_j)$ is monotonic then firm i's payoff function, equation (3.1), has the weak single crossing property in $(b_i;s_j)$. It can also be verified that (3.1) is supermodular in $(b_i;s_i)$ and $(b_i;-D_i)$. (Here I use the reverse order for debt). This implies the single crossing property in $(b_i;s_i)$ and $(b_i;-D_i)$ from Athey(1994) theorem 5.1. This means "that the set of best replies for firm i is nondecreasing in s_i and $-D_i$ (and in particular the lowest and highest solutions are nondecreasing)." Thus, the bid of firm i is nondecreasing in signal, and nonincreasing in debt level. This is a supermodular game, and thus a pure strategy Nash equilibrium exists (by Milgrom and Roberts (1990), expanded by Milgrom and Shannon (1994)).

Proposition 6 states that as a firm increases its debt level, it bids less competitively and the rival also lowers its bid. When a firm lowers its bid this has two effects on the expected payoff to the firm. First, the probability it wins the auction is lower, which lowers expected payoff, but the amount of money the firm makes if it wins the auction is higher. In essence the return to the firm is made riskier by lowering the bid; thus, this result is consistent with the result that as a firm has more risky debt the equityholders want the firm to make the payoff of the firm more risky, even if it involves lowering the expected value of the firm as a whole. A lower bid has two affects on the competitor's decision. When one firm lowers its bid this mitigates the winner's curse problem which allows the competitor to increase its bid, because now the expected value of the object conditional on winning is higher. In addition, the auction is now less competitive and the competitor has a higher probability of winning the auction at each bid, this allows the competitor to decrease its bid and thus increase the payoff if it wins the auction. The second effect dominates the reduction in the winner's curse and hence both firms reduce their bid when one firm increases its debt level.

COROLLARY: *As the players' debt levels increase the expected revenue generated by the auction decreases.*

With both firms lowering their bid this lowers the expected revenue to the seller.

3. Evidence from FCC spectrum auctions

With the enormous expansion of communications and of the broadcast media in recent years, the government has started auctioning off the airwaves, which previously had essentially been given away, free of charge, to radio and TV stations, telephone companies and others, complying with certain regulatory restrictions. There have been a large number of auctions in recent years, employing reasonably complex rules. The auction considered in this paper is of blocks A and B in 51 Metropolitan areas (except for New York, Los Angeles, and Washington D.C. where only block B was auctioned). In each area, there were already two incumbents, each holding title to a 25 MHz band. A and B licenses allowed a third and a fourth competitor to come in, each receiving title to a 30 MHz band. This spectrum was supposed to be for "personal communication", which has a broad legal meaning, but it was well suited for digital cellular communication including fax and data transmission. The winning bidders had to pay the amount bid in cash.[16]

Bidding was in as many rounds as were needed to decide a winner – each time any bidder was willing to up the bid, bidding for all other areas was re-opened and bidders were allowed to increase bids there too. The theory (supported by our empirical work) was that there might be synergies between areas. Effectively, markets closed from big to small because of some other rules regarding how bids can be added and dropped. The total number of rounds was 112.

In this section, we use the FCC auction data for blocks A and B to test the theory that the highest bid submitted by a company (not necessarily the winning bid) was affected by its capital structure. Clearly, there is some difference between the model and the actual auction. As in the case of all papers dealing with the impact of capital structure on product market decisions, the model assumes essentially that each firm only has one project (although we did allow for cash at hand) whereas in reality firms had several lines of business. However, in many of these cases, the projects in question were substantial, and thus, if the model has empirical content, one should expect to find some effect.

The main source of data was the FCC web site (FCC.Gov) that listed all bids in all auctions. A program (MTATrack.xls for excel applications) enabled us to navigate this massive data source and consider various facets of that data set . The bids considered for this experiment were the final bids submitted by the company in

---

[16] As opposed to the later auction of C blocks, i.e., additional competitors in a different spectrum band who had to post only a 10% down payment. In that latter auction, bidding reached stratospheric heights, and in 1997 several important bidders were on the verge of bankruptcy. The FCC had to come up with a plan, adopted with a narrow majority, to save the auction (see New York Times September 26th, 1997 p. D1). Auction in later blocks were being investigated in 1997 for collusion and fraud. A and B are thus the "cleanest" and closest to our model.

question, before it either won or it dropped out of the race. Since the two blocks, A and B, were essentially identical, we only considered the highest bid between the two for each company (some companies would quickly drop out of bidding for block A but kept bidding for block B).

Thirty companies participated in the bidding for the various metropolitan areas. Some companies were limited partnerships, others were privately held (for example, ALAACR was privately held by Craig McCaw). For other companies we could find no additional identifying information. We ended up with 14 companies, for which a complete data set could be assembled, leading to 154 company-bid pairs. (See appendix B for a list of all companies in the auction).[17] The number of company-bid pairs was relatively large, because obviously we did have information about the largest and generally most active companies.[18] Company information was generally obtained from Compustat for the yearend 1994, which is approximately when the auction took place (the auction started in December of1994 and ended in March of 1995).

For leverage, we used book value ratios as well as market value ratios. The market value ratios were computed using stock prices as of December 31st 1994. We adjusted bond prices as follows: from S&P bond guide we obtained bond price information for presumably all publicly traded bonds of the companies in question. We adjusted the book value of the bonds for which we had information to reflect market values. For example, if a bond was listed at a price of 102, we increased the price of the bond in the book measure by 2%. The rest of the debt, for which there was no market value information, was listed by book value. Other Compustat information included sales and total assets.

We constructed two additional variables for use in our regressions – one reflected the synergies of adjacent areas. This variable received a value of 1 if the company in question won in a previous round a license in an adjacent market and zero otherwise. A second variable reflected the market value weighted capital structure of all firms bidding in a specific market except the firm in question – again, we used both market value and book value measures. The purpose is to measure the capital structure of competitors, which is one of the elements included in our theory.

Clearly, bids are also strongly influenced by the number of people in each area and their economic status. Our dependent variable is thus stated in terms of dollars per

[17] The most active bidder, Wireless Co. is a partnership of Sprint, Tele-Communications, Cox Cable and Comcast. We formed a weighted average for all company data based upon the weights in the partnership (40%, 20%, 20%, 20% respectively).

[18] Note, however, that our theory relates to bidding behavior and therefore is applicable to each bid by each company rather than to total bidding behavior.

person (this is also the common way these bids are described by professionals and in the press). Population information is listed in the FCC site, referring apparently to the number of people who can be reached by the winner. We used additional data out of Demographics USA (1997) which listed population in different metropolitan areas, total disposable income in each area as well as projected income growth. This information was used to calculate income per capita for each of the areas in question.

RESULTS

We use the high bid per capita, that each firm submitted, as the dependent variable. An OLS regression is used to find out if leverage plays a role in determining the highest bid each firm is willing to submit for a particular metropolitan area. According to our theory, an increase in leverage should cause a decrease in the high bid for the firm. In addition, an increase in the leverage of the competition should also decrease the high bid for the firm. We run regressions with both market values of debt to equity and book values of debt to equity. We include additional variables that may affect the high bid, such as income per capita, an adjacent dummy, and a size variable - either the natural log of assets or the natural log of sales.

The first regression uses the market debt to equity ratios, natural log of sales, as well as, the adjacent dummy, and income per capita as the independent variables (see table 2). The market debt to equity ratio has a negative coefficient and has a p-value of .0907. This means that as the firm's D/E ratio increases it will submit a lower bid. The D/E ratio of the competition also is negative (p = .0290). Thus, as the competition increases leverage, this is also associated with a lower bid. As expected, income per capita, and adjacent both have positive coefficients (p = .0139 and p = .0284). This implies that firms bid more for a region with a higher per capita income, and have higher bids in regions that are adjacent to regions in which they won the franchise. The size proxy was positive, but it was not significant at any reasonable level.

We also examine the same regression using log of assets instead of log of sales to control for firm size (see table 3). The results are essentially the same. The coefficients of the market debt to equity ratio of the bidding firm and of the competition are both negative. The adjacent market dummy and the income per capita variables both have positive and significant coefficients. The size variable is insignificant.

The third regression uses book debt to equity ratios instead of the market values, as well as, the adjacent dummy, income per capita, and log of assets. The book debt to equity ratio of the firm and its competitors both have negative coefficients, but they are not significant. Income per capita and adjacent are both positive (p = .0061 and p = .0345) and log of assets is insignificant. The leverage variables enter the regression with the anticipated sign (both are negative), but they are not significant.

These results are consistent with the hypothesis that as leverage increases the firm's bid decreases. In addition, there is strong evidence that as the leverage of the competition increases, the firm's bid decreases. We also identify two other factors that are significant in the FCC auction. First, the income per capita is important to the value of a metropolitan region, and thus, has an important impact on the bid a firm submits for a region. Second, if a firm is winning an adjacent region this has a significant positive affect on the firm's bid for a region. This implies that there are synergies from owning rights in adjacent metropolitan regions.

4. Conclusion

This paper presents a theoretical model predicting how leverage should affect bidding behavior. It is shown that both the degree of leverage of the bidding firm and the debt ratio of the competition are important factors in the bid a firm is willing to submit in an auction. In particular, as the firm increases its debt level, the highest bid it is willing to submit decrease. As the competition increases its debt level, this also causes the firm to decrease its high bid.

We investigate an FCC auction to determine if the effect of debt on bidding behavior is important empirically. The results show that as a firm's own debt level and as the competitions' debt levels increase, firms tend to submit lower bids. This supports the theoretical model developed in this paper.

References:

Allen, F.(1987) "Capital Structure and Imperfect Competition in Product Markets" Discussion paper, University of Pennsylvania.

Brander, J. and T.R. Lewis (1986) "Oligopoly and Financial Structure: the Limited Liability Effect" American Economic Review, December, pp.956-970.

Chevalier, -J, A.: (1995a) Do LBO Supermarkets Charge More? An Empirical Analysis of the Effects of LBOs on Supermarket Pricing Journal-of-Finance; 50(4), September, pages 1095-1112.

Chevalier,-J, A.: (1995b) Capital Structure and Product Market Competition: An Empirical Study of Supermarket LBO's American Economic Review; 85,June, pp. 415-435.

Clayton, Matthew J., 1997, "Debt, Investment, and Product Market Competition," New York University, Working Paper.

Dammon, R. and L. Senbet (1988) "The Effects of Taxes on the Interaction between Production and Finance" Journal of Finance, June, pp.357-374

De-Angelo, H. and R.W. Masulis(1980) "Optimal Capital Structure Under Corporate and Personal Taxation" Journal of Financial Economics March, pp.3-29

Dotan, A. and S.A.Ravid (1985) "On the Interaction of Real and Financial Decisions of the Firm Under Uncertainty" Journal of Finance, June, pp.501-517.

Dybvig,P.H. and Zender,J.F. (1991) "Capital Structure and Dividend Irrelevance with Asymmetric Information" Review of Financial Studies, 4(1), pages 201-19.

French, K. and R. McCormick, 1984, "Sealed Bids, Sunk Costs, and the Process of Competition," Journal of Business, 57: 417-441.

Griesmer, J., R. Levitan, and M. Shubik, "Towards a Study of Bidding Processes Part IV - Games with Unknown Costs," Naval Research Logistics Quarterly, December 1967, 14: 415-33.

Hendricks, K., R. Porter, and B. Boudreau, 1987, "Information and Returns in OCS Auctions: 1954-69," Journal of Industrial Economics, 35: 517-542.

Hite, G.L. (1979) "Leverage, Output Effects and the M-M Theorems", Journal of Financial Economics, March, pp.177-202.

Holt, C., "Competitive Bidding for Contracts under Alternative Auction Procedures," Journal of Political Economy, June 1980, 88: 433-45.

Jensen, M., and H. Meckling, "Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure," Journal of Financial Economics, October 1976, 3: 305-360.

Maskin, E., and J. Riley, "Optimal Auctions With Risk Averse Buyers," Econometrica, November 1984, 52: 1473-518.

Maskin, E., and J. Riley, "Auctions Theory with Private Values," American Economic Review, May 1985, 75: 150-5.

Maksimovic, V. (1988) "Capital Structure in Repeated Oligopolies" Rand Journal of Economics, Vol. 19 #3, pp.389-407.

Maskin, E., and J. Riley, "Asymmetric Auctions," October 1994, MIMEO.

Milgrom, P. (1989) "Auctions and Bidding: A Primer" Journal of Economic Perspectives, Summer 3: 3-22.

Milgrom, P., and R. Weber, "A Theory of Auctions and Competitive Bidding," Econometrica, September 1982, 50: 1089-122.

Myers, S.C. (1977) "Determinants of Corporate Borrowing" Journal of Financial Economics, November, pp.147-176.

Myerson R., "Optimal Auction Design," Mathematics of Operations Research, 1981, 6: 58-73.

Phillips, G.M. (1995) "Increased Debt and Industry Product Markets-An Empirical Analysis" Journal of Financial Economics, 37, pp. 189-238.

Porter, R., 1995, "The Role of Information in U.S. Offshore Oil and Gas Lease Auctions,"
Econometrica, 63: 1-27.

Ravid, S.A. (1988) "On Interactions between Production and Financial Decisions", Financial Management, Fall, pp.87-99.

Ravid, S. A., 1997, "Leverage Changes And Product Pricing Incentives-
A Tax Induced Analysis," Working Paper.

Rice, J., 1988. Mathematical Statistics and Data Analysis.

Riley, J., and W. Samuelson, "Optimal Auctions," American Economic Review, June 1981, 71: 381-92.

Robinson, M., "Collusion and the Choice of Auction," Rand Journal of Economics. Spring 1985, 16, 1: 141-145.

Smiley, A., 1979, "Competitive Bidding Under Uncertainty: The Case of Offshore Oil," Cambridge: Ballinger Press.

Wilson, R., 1977, "A Bidding Model of Perfect Competition," Review of Economic Studies, 44: 511-518.

Vickrey, W., "Counterspeculation, Auctions, and Competitive Sealed Tenders" Journal of Finance, March 1961 16, 1: 8-37.

APPENDIX

[insert appendix here]

Definition of variables:

EBIPRCAP - Earnings per capita
HBIDPRCP - The highest bid the firm submits per capita
ADJACENT - Dummy variable = 1 if the firm won an adjacent area
LSALES94 - Natural log of total sales for 1994
LTASST94 - Natural log of total assets for 1994
BDASST94 - Book debt to equity ratio for 1994
BCMPDE94 - Book debt to equity ratio for the competition in 1994
MKMKDE94 - Market debt to equity ratio for 1994
MCMPDE94 - Market debt to equity ratio for the competition in 1994

Table 1: Descriptive statistics of variables.

Number of observations: 154

Variable	Mean	S.D.	Maximum	Minimum
EBIPRCAP	15.582862	2.2899521	20.078900	5.1242300
HBIDPRCP	12.492910	7.6830098	31.902300	0.6000900
ADJACENT	0.2142857	0.4116647	1.0000000	0.0000000
LSALES94	9.0838984	1.4669210	11.226500	6.0323350
LTASST94	9.7617097	1.1158875	11.280510	7.5361880
BDASST94	0.7115778	0.1299699	1.1754320	0.4566311
MKMKDE94	0.4379180	0.4295429	3.7792030	0.0354722
MCMPDE94	0.4623256	0.2547566	0.8960950	0.0354720

Table 2: OLS Regression 1.

Dependent variable is high bid. Regressors include the market debt to equity ration of the bidding firm (MKMKDE94) and the competition (MCMPDE94).

Number of observations: 154

VARIABLE	COEFF	STD. ERR	T-STAT.	2-TAIL SIG.
C	0.3425466	5.8485644	0.0585693	0.9534
MKMKDE94	-2.4753999	1.4538315	-1.7026731	0.0907
LSALES94	0.5278631	0.4234992	1.2464324	0.2146
EBIPRCAP	0.6514893	0.2616279	2.4901372	0.0139
ADJACENT	3.2241727	1.4570081	2.2128723	0.0284
MCMPDE94	-5.1990015	2.3584360	-2.2044276	0.0290

R-squared	0.118233	Mean of dependent var	12.49291
Adjusted R-squared	0.088444	S.D. of dependent var	7.683010
S.E. of regression	7.335388	Sum of squared resid	7963.572

Table 3: OLS regression 2.

Dependent variable is high bid (HBIDPRCP). Regressors include the market debt to equity ratio of the firm (MKMKDE94) and the competition (MCMPDE94).

Number of observations: 154

VARIABLE	COEFFICIENT	STD. ERR	T-STAT.	2-TAIL SIG.
C	-0.9066062	6.9173247	-0.1310631	0.8959
MKMKDE94	-2.3997088	1.4485667	-1.6566091	0.0997
LTASST94	0.6212892	0.5521935	1.1251295	0.2624
EBIPRCAP	0.6479394	0.2618391	2.4745711	0.0145
ADJACENT	3.2997302	1.4541268	2.2692176	0.0247
MCMPDE94	-5.2307061	2.3606428	-2.2157973	0.0282

R-squared	0.116534	Mean of dependent var	12.49291
Adjusted R-squared	0.086687	S.D. of dependent var	7.683010
S.E. of regression	7.342453	Sum of squared resid	7978.920

Table 3: OLS regression 3.

Dependent variable is high bid (HBIDPRCP). Regressors include the book debt to equity ratio of the firm (BDASST94) and the competition (BCMPDE94), and the natural log of total assets (LTASST94).

Number of observations: 154

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	-1.7399966	7.7735661	-0.2238351	0.8232
BDASST94	-1.9020206	6.0147996	-0.3162234	0.7523
LTASST94	0.4991430	0.6864108	0.7271782	0.4683
EBIPRCAP	0.7381125	0.2654980	2.7801051	0.0061
ADJACENT	3.2911146	1.5426565	2.1334073	0.0345
BCMPDE94	-0.5131347	0.9698320	-0.5290965	0.5975

R-squared	0.077669	Mean of dependent var	12.49291
Adjusted R-squared	0.046510	S.D. of dependent var	7.683010
S.E. of regression	7.502216	Sum of squared resid	8329.920